FERTILITY-BASED HERBICIDE INJURY RECOVERY FROM CLOMAZONE IN HYBRID RICE (*Oryza sativa* L.)

A Thesis

by

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ABSTRACT

Clomazone is a carotenoid biosynthesis inhibitor commonly used as a preemergence and postemergence herbicide in rice for the control of grass weeds. Rice injury can occur and symptoms are often associated with soil characteristics and environmental conditions. The objective of this research was to investigate how environmental conditions and planting density influence clomazone injury in rice plants. Also, different fertility treatments were assessed to determine if remediation from clomazone injury occurred. Field studies were conducted in 2008 and 2009 to determine the role of planting date, planting density and soil characteristics on clomazone injury in rice plants. Also, another field study was conducted in 2010 to assess any clomazone injury remediation benefits selected fertility treatments might have in rice cropping systems.

In the 2008 and 2009 field studies, hybrid rice was seeded at three densities that comprised a range of slightly lower, slightly higher and commonly recommended planting rates. Two planting dates, March and April, were a test parameter to simulate early and optimal planting dates. Two locations with different soil characteristics, near Eagle Lake and Beaumont, TX, were the study sites. Clomazone herbicide treatments were applied at different rates and timings following planting. Visual injury ratings and yield data were collected during this two-year, two location study.

Clomazone injury in rice was more severe in the coarse-textured soils planted at the early, March planting date near Eagle Lake. Visual injury ratings as high as 90%

were observed in some plots. Injury was less severe in the April planting date near Eagle Lake, and at both planting timings near Beaumont. In both locations, clomazone injury did not translate into yield loss at any seeding rate or planting timing.

In 2010, field studies were conducted near Eagle Lake and Ganado, TX to assess fertility-based clomazone injury remediation. In one experiment, hybrid rice plots were subject to linearly increasing rates of clomazone herbicide to produce a standard curve of clomazone injury. In the second experiment, a uniform, label rate of clomazone was applied to induce injury for the assessment of the effect of fertility amendments on clomazone-injured rice. Fertility treatments consisted of nitrogen-based fertilizers and foliar-applied iron sulfate and magnesium sulfate. Visual injury ratings, plant height, and yield were collected during the study. Also, tissue samples were collected three times for laboratory analysis of chlorophyll content.

In the standard curve experiment, herbicide injury increased with increasingly higher rates of clomazone applied. The highest visual injury was observed in plots receiving the highest rates of clomazone. In the remediation experiment, fertility treatments had a significant effect in only one tissue-sampling event at Eagle Lake as determined by laboratory analysis for chlorophyll content. Fertility amendments did not have a significant effect on visual injury ratings at either location at any assessment event. Specific fertility treatments significantly increased plant height in three measurement events, and yield at the Ganado locations. Plots receiving treatments containing nitrogen fertilizers produced taller plants at both locations, and increased yield at the Ganado location.

DEDICATION

I would like to dedicate this work to my parents, Travis and Linda. Their constant support, sacrifice and love have made it possible for me to achieve many lifelong goals. Thank you for instilling in me an appreciation for education. I would also like to dedicate this thesis to my aunt, Debra, whose strength and determination motivates and inspires me.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

Rice (*Oryza sativa* L.) is an important crop grown worldwide and accounts for more than half of the world's primary staple (Anonymous 2008). In 2009, the top rice-producing countries were located in Asia. China is the largest rice-producer with 137 million metric tons being produced in 2009. The United States is ranked eleventh in rice production on the global scale with 6.9 million metric tons produced in 2009 (USDA FAS 2010).

The United States Department of Agriculture identifies four geographical regions within the United States where rice is produced. These regions include the Arkansas Grand Prairie, the Mississippi Delta, coastal regions along the Gulf of Mexico in Texas and Louisiana, and the Sacramento Valley of California. Of the six states that commonly produce rice, Texas ranked sixth in both grain yield and value of production in 2009, harvesting approximately 600 million kg of rice on 68,796 ha (USDA ERS 2010).

In Texas, rice is typically grown in the major land resource area known as the Gulf Coast Prairies. This area lies on the Gulf Coast from Jefferson and Orange counties in the eastern coastal region, to Victoria and Calhoun counties in the central coastal region of the state. The average yield in 2009 was about 8710 kg/ha (USDA ERS 2010). Texas rice production sites are generally rotated with traditionally grown field crops, improved pasture for livestock grazing, or ponds for crawfish production.

Economic factors involved with rice production include milling and cost of production. Producers can be docked in sale prices for lower quality grain that lacks integrity during the milling process (Koutroubas et al. 2004). Losses in this process can be significant considering the cost of production. The sources of high production costs include flood irrigation, capital expenses, fertilizer inputs, and crop protection from disease, insects, and weeds.

Several species of broadleaves and grasses are considered weeds in rice production. Weeds cause problems by competing with rice for nutrients and sunlight (Willingham et al. 2008). Annual grass control is critical in optimizing rice yield (Smith and Hill 1990). A weed management program including effective control of these grassy weeds is necessary to enhance the productivity of rice cropping systems in Texas. Clomazone, 2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone, is a herbicide classified within the isoxazolidinone chemical family. The mode of action is classified as a carotenoid biosynthesis inhibitor and typical symptoms include bleached, white above-ground plant tissue that becomes necrotic after several days. Clomazone is metabolized in the plant to the active form, 5-keto clomazone. This 5-keto form inhibits 1-deoxy-D-xyulose 5-phosphate synthase (DOXP), which is a necessary component to the synthesis of plastid isoprenoids (Mallory-Smith and Retzinger 2003). Currently, clomazone is registered for use in rice (*Oryza sativa*), soybean (*Glycine max* (L.) Merr.), cotton (*Gossyium spp.*), tobacco (*Nicotiana tabacum* L.), sugarcane (*Saccharum spp.*), and several vegetable crops under various state registrations (Senseman 2007).

In research aimed at clomazone interaction with vegetable crops, Grey et al. (2000) concluded that clomazone applied preemergence (PRE) at rates ranging from 0.56 to 1.12 kg ha^{-1} had few or no effects on maturity, early-season growth, stand or yield in yellow or zucchini squash (*Cucurbita pepo* L.). In 1993, Grey et al. also observed good plant establishment, stand and yield in different pepper (*Capsicum annuum* L.) cultivars when clomazone was applied post-transplant (PT) at the same rate range of 0.56 to 1.12 kg ha^{-1} (Grey et al. 2001). In a row crop study, Sikkema et al. (2007) reported that clomazone applied at rates of 1.12 and 2.23 kg ha^{-1} injured dry beans (*Phaseolus vulgaris* L.). Injury was most severe 7 days after emergence (DAE) but was minimal 28 DAE. No reduction in plant height, shoot dry weight or yield was observed at the conclusion of the study.

Richard and Griffin (1993) assessed clomazone crop injury and efficacy as a PRE herbicide for the control of johnsongrass (*Sorghum halapense* (L.) Pers.) in sugarcane production systems. Sugarcane plants receiving clomazone were injured 7 days after treatment, but visual injury symptoms had dissipated 8 weeks after treatment. Despite early-season injury, no reduction in shoot height or number was observed. In a study by Langton et al. (1997), clomazone efficacy was evaluated in applications made prior to planting. When applied 45, 30, 15, or 0 days prior to the planting of soybeans, clomazone provided season-long control of velvetleaf (*Abutilon theophrasti* Medik) and giant foxtail (*Setaria faberi* Herm.). In a sweet potato (*Ipomoea batatas*(L.) Lam.) production system, Porter (1990) observed ≥ 90% control of broadleaf signalgrass (*Urochloa platyphylla* (Nash) Webster), large crabgrass (*Digitaria sanguinalis* (L.)

Scop.), barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), and prickly sida (*Sida spinosa* L.) when clomazone was applied preplant incorporated or PT. Common cocklebur (*Xanthium strumarium* L.) control was also observed as high as 93% and no crop injury was detected within any clomazone treatment.

Clomazone was registered for rice in 2001 and is applied PRE and early post-emergence (EPOST) in dry- and water-seeded rice production, providing effective control of barnyardgrass, various sprangletop species (*Leptochloa spp.*), and broadleaf signalgrass (Anonymous 2007; Willingham et al. 2008). The commonly used formulation of clomazone in Texas rice production is Command 3ME®. The label recommends a single PRE application rate of 0.28 kg a.i./ha on coarse-textured soils and up to 0.67 kg ha^{-1} on fine-textured soils. A split application may also be administered, where the first application is made PRE followed by a second application EPOST. Rates for the first PRE application range from 0.28 kg/ha on coarse-textured soils to 0.56 kg ha^{-1} on fine-textured soils. For the second EPOST application, recommended rates range from 0.11 kg ha^{-1} on fine-textured soils to 0.33 kg ha^{-1} on medium-textured soils (Anonymous 2011). Texas Rice Production Guidelines recommend a rate range of 0.45 kg $ha^{-1}$to 0.67 kg ha^{-1} (McCauley and Senseman 2012).

Literature Review

Past research suggests that clomazone is effective at season-long control of annual grass weeds in rice. Webster et al. (1999) indicated that a single application of clomazone can control barnyardgrass throughout the season, and rice yields were equal to standard weed control programs. O'Barr et al. (2007) reported barnyardgrass control of >88% at 42 to 58 days after treatment (DAT) when clomazone was applied at rates of 0.34 kg ha^{-1} and higher. Research conducted by Zhang et al. (2004) suggests that using clomazone at higher rates may increase rice grain yield through improved weed control. Although rice has shown acceptable tolerance to clomazone, substantial injury can occur under certain environmental conditions (Mitchell and Hatfield 1996). Injury is generally greater when rice is grown on coarse-textured soils. Visual injury symptoms usually occur early in the season and diminish over time. O'Barr et al. (2007) reported rice injury in coarse-textured soils near Ganado and Eagle Lake, TX. The study near Ganado showed rice injury of 49% 16 DAT, and visual rice injury of 60% was observed 19 DAT near Eagle Lake. Data collected 45 to 53 days later showed that rice had recovered and injury was minimal at Ganado (4%) and Eagle Lake (15%).

Other research suggests that rice varieties may respond differently to clomazone injury. Mudge et al. (2005) concluded that a short-grain variety (Pirogue) showed greater clomazone injury than medium and long-grain varieties, which resulted in a yield loss of 1,740 kg ha^{-1}. Hybrid rice varieties may respond differently to clomazone treatment compared with conventional varieties because of their lower recommended seeding rate. This warrants further research on the response of hybrid rice varieties to clomazone. The potential for early season phytotoxicity from clomazone may overshadow its efficacy as a weed control option for Texas rice producers. Using fertility treatments common to rice production may be a viable option to reduce injury symptoms or increase the rate of plant recovery from injury. Because of the high cost involved with rice production, potential remediation options should fit within the established fertility program and management practices at little or no additional production costs.

Hybrid rice acreage has increased significantly in recent years with 17,554 ha reported grown in Texas during 2011 (Tabien et al. 2012). Thus, further examination of clomazone-rice interaction is warranted when hybrids are planted at lower, recommended seeding rates. Also, research conducted on fertility-based remediation of clomazone-injured rice may enhance management and fertility recommendations for producers that include clomazone within their weed management practices.

CHAPTER II

HYBRID RICE TOLERANCE TO CLOMAZONE AS AFFECTED BY PLANTING DATE AND SOIL CHARACTERISTICS

Introduction

Recommended seeding rates for hybrid rice is much lower than seeding rates for conventional varieties (Blanche et al. 2009). Current Texas Rice Production Guidelines indicate that an adequate stand for conventional, semidwarf varieties is 86 to 108 seedlings per square meter (McCauley et al. 2012). Because of differences that may exist between hybrid lines, it is recommended that producers consult the hybrid seed representative for planting guidelines and recommended seeding rates (Blanche et al. 2009).

Depending on location, recommended planting dates for rice in Texas are different. Texas Rice Production Guidelines recommend that rice be planted from March 15 to April 21 in the western growing area, and from March 21 to April 21 in the eastern growing area (Dou and Tarpley 2012). Planting is not recommended when the 10 cm minimum soil temperature falls below 18° C. Cooler environmental conditions may exist at earlier planting dates. Clomazone is typically applied PRE and early season injury to rice plants can occur (O'Barr et al. 2007). Hybrids planted at the lower, recommended planting rate might potentially show greater injury as fewer plants are exposed to the recommended application rate of clomazone for effective weed control.

The percentage of hybrids in total Texas rice production has increased in recent years. In 2010, rice production occurred on 71,232 ha with 13,051 ha of hybrid production reported. In comparison, 2011 rice production occurred on 73,556 ha with 17,554 ha of hybrid production reported (Tabien et al. 2012). This represents an increase in reported production with hybrid lines from 18% of total production in 2010, to 24% of total production in 2011. Standard weed management practices for conventional varieties are the same recommended for hybrids, including the use of clomazone PRE and EPOST for control of grassy weeds at recommended rates.

Clomazone rates recommended for rice production vary among soil texture on the site where production will occur. For a single PRE application on coarse-textured soils, 0.28 kg ha^{-1} is the recommended rate (Anonymous 2011). For a single PRE application on fine-textured soils, 0.67 kg ha^{-1} is the highest recommended rate (Anonymous 2011). If a PRE and EPOST split-application is applied, a rate of 0.28 kg ha^{-1} PRE followed by 0.28 kg ha^{-1} EPOST is the recommended rate on coarse-textured soils. In a split-application on fine-textured soils, a rate of 0.56 kg ha^{-1} PRE followed by 0.22 kg ha^{-1} EPOST is recommended by the product label (Anonymous 2011). Texas Rice Production Guidelines recommend a rate range of 0.45 to 0.67 kg ha^{-1} (McCauley and Senseman 2012). The objective of this study is to assess herbicide injury interaction between three hybrid rice seeding densities, and different rates of clomazone applied PRE and EPOST.

Materials and Methods

Field studies were conducted in 2008 and 2009 at the Texas AgriLife Research and Extension Center near Beaumont, TX and the Texas AgriLife Research Station near Eagle Lake, TX. Studies near Beaumont were planted into a Morey silty clay loam with 19.4% sand, 45.3% silt, 35.5% clay, and a pH of 7.3. Studies near Eagle Lake were planted into a Nada fine sandy loam with 61.4% sand, 31.2% silt, 7.4% clay, and a pH of 6.1. Both field locations were in a rice-fallow rotation system where rice was planted every three years with fallow periods between. Before study establishment, the field was cultivated and an adequate seedbed was prepared with proper slope for flood irrigation practices.

Two planting timings, March and April, were selected to simulate a typical scenario for planting in Texas. The March planting date simulates an early planting date for both locations, near Beaumont and Eagle Lake. April planting dates were near the time when guidelines suggest may be too late to maximize yield and ratoon potential (Dou and Tarpley 2012). In 2008, “XL723” hybrid rice was drill seeded on March 26 and April 23 near Beaumont. In 2008 near Eagle Lake, “XL723” hybrid rice was drill seeded March 24 and April 16. In 2009, “XL723” was again drill seeded near Beaumont on March 12 and April 9. Near Eagle Lake in 2009, “XL723” was drill seeded March 23 and April 15. Three different seeding rates were planted at both locations. To best simulate a range of recommended planting rates, 28, 39 and 50 kg ha^{-1} of seed was drill seeded.

The experimental design was a randomized complete block design with four replications. Plot size near Beaumont measured 1.5 m wide and 5.5 m long. Plots near Eagle Lake measured 1.5 m wide and 4.9 m long. Plot size remained the same at each location for both study years. Plots consisted of 7 rows of hybrid rice spaced 19 cm apart and each plot was separated by an alley approximately 0.3 m wide. Plot areas at both locations were in a rice-fallow rotation with rice being grown every third year.

Before planting occurred, pre-plant fertilizers were applied to both field locations. Near Beaumont 53 kg ha^{-1} of nitrogen (N), 53 kg ha^{-1} of P_2O_5, and 53 kg ha^{-1} of K_2O were applied to simulate typical fertility management practices following soil tests for nutrients. Near Eagle Lake 53 kg ha^{-1} of N, 53 kg ha^{-1} of P_2O_5, and 53 kg ha^{-1} of K_2O were also applied at the preplant timing. Nitrogen (N), phosphorus (P) and potassium (K) were applied in the form of urea, triple super phosphate and potassium chloride. Subsequent fertility applications included nitrogen-containing fertilizers at timings and rates recommended by Texas Rice Production Guidelines (Dou and Tarpley 2012). Urea was applied to provide 79 kg ha^{-1} of N at the preflood timing at both study locations. Ammonium sulfate was applied to provide 89 kg ha^{-1} of N at both locations when the majority of rice plants were at the panicle initiation growth stage.

After planting, a cultipacker implement was used to smooth the seedbed and PRE herbicide treatments were applied. All plots received a PRE application of clomazone except for weed-free check plots. The weed-free check plots received an EPOST, tank-mixed treatment of propanil, (*N*-(3,4-dichlorophenyl) propanamide), at 3.36 kg ha^{-1} and quinclorac, (3,7-dichloro-8-quinolinecarboxylic acid), at 0.56 kg ha^{-1}. Clomazone rates for the PRE application near Eagle Lake included 0.28, 0.33, and 0.42 kg ha^{-1}. PRE treatment rates near Beaumont included 0.34, 0.42 and 0.56 kg ha^{-1}. In 2008 near Beaumont, PRE applications were made on March 26 and April 23. The 2008 study near Eagle Lake received PRE applications March 24 and April 16. In 2009 near Beaumont, PRE clomazone applications were applied March 12 and April 9. Near Eagle Lake in 2009, applications were made March 23 and April 15. Soon after the initial herbicide application fields were flushed as recommended by Texas Rice Production Guidelines to induce germination of rice and weed seed.

Treatments receiving split applications of clomazone received the EPOST application when most rice seedlings were at the 1- to 2-leaf growth stage. Three EPOST rates were used near Beaumont and Eagle Lake among the treatments. Near Beaumont, EPOST rates included 0.34, 0.42, and 0.56 kg ha^{-1}. Near Eagle Lake, EPOST rates included 0.28, 0.34, and 0.42 kg ha^{-1}. EPOST applications in 2008 were made near Beaumont on April 29 and May 12. Near Eagle Lake, 2008 EPOST applications were made April 21 and May 7. In the 2009 study near Beaumont, clomazone was applied EPOST on April 9 and May 4. Near Eagle Lake in 2009, EPOST applications were made April 15 and May 1. All herbicide treatments were delivered with a spray boom containing three flat-fan nozzles (Teejet XR10002, Spraying Systems Co., Wheaton, IL) spaced 50 cm apart. The boom was attached to a 3-L spray solution reservoir and pressurized with a CO_2 backpack sprayer adjusted to deliver 140 L ha^{-1} of spray solution at 172 kPa.

Following the EPOST application timing, visual injury ratings were collected. Visual ratings were assigned to each plot on a percentage basis, and were an estimation of white, above-ground plant tissue within each plot. A visual injury rating of 0% indicated that no visual injury symptoms were detected. A visual injury rating of 50% indicated that approximately half of all above-ground plant tissue within that plot showed symptoms characteristic of clomazone injury, while a visual injury rating of 100% indicated that total plant death had occurred within that particular plot. Field sites received a flush of irrigation water at timings recommended by Texas Rice Production Guidelines until a flood was established that would remain in place for the duration of the growth cycle until physiological maturity.

At the conclusion of the study, fields were drained and rice grain was harvested when moisture content was approximately 20%. Four rows from each plot were harvested using a mechanical harvester (Mitsubishi VM221KC, Mitsubishi Agricultural Machinery Co., Higashiizumo, Shimane, Japan). Grain weight and moisture content was collected using an electronic scale (Mettler-Toledo BBA 422-35SM, Mettler-Toledo, L.L.C., Columbus, OH) and moisture analyzer (DICKY-john GAC2100b, DICKY-john Co., Auburn, IL). Grain weight was then adjusted to 12% moisture and converted to kg ha^{-1}. All visual injury rating and yield data were subjected to analysis of variance (ANOVA) with the PROC MIXED procedure using SAS computer software (Statistical Analysis Systems, 9.2 Software, SAS Institute Inc., Cary, NC). Visual injury values were subjected to arcsine transformation before statistical analysis. Following the initial ANOVA procedure, data were subject to Hartley's test for homogeneity to determine if years and locations could be combined. Means for significant effects were separated using Tukey's Test ($p \leq 0.05$).

Results and Discussion

Following an initial ANOVA, maximum and minimum sum of squares values for each visual assessment and yield data collection were used in Hartley's Test for homogeneity to determine if years and locations could be combined. The maximum sum of squares value from both locations and both years were divided by the minimum sum of squares value to obtain the Hartley's Test value. After determining the value was less than the corresponding p-value according to the homogeneity test, both years and locations could be combined for yield analysis. Years and locations were analyzed together within each of the two different planting timings, March and April. Subsequent Hartley's Tests indicated that the first visual injury ratings from the March planting date in 2008 and 2009 could be combined within years at the Beaumont location. The first visual injury rating assessment at the Eagle Lake location from 2008 and 2009 could also be combined within years. In 2008, visual injury was not detectable at either locations at the time of the second visual assessment. In 2009, injury was detected at the second visual assessment at both Beaumont and Eagle Lake, and a third assessment indicated visually detectable clomazone injury at the Eagle Lake location. Second and third visual assessment timing injury data for March planting timings were analyzed independently. In the April planting timing study at Eagle Lake, the first visual injury assessment data could be combined within years according to Hartley's Test. No visual injury was detected in 2008 at the Beaumont location; however, clomazone injury was observed in 2009 and was analyzed independently. At the time of the second visual injury assessment within the April planting timing, injury was only observed in 2009 at the Eagle Lake location and was also analyzed independently.

March Planting Date. Following the initial statistical analysis and Hartley's Test for homogeneity to determine which test parameters could be combined within year or location, a combined ANOVA was performed (Table 1). Data from test parameters not homogeneous were analyzed independently.

Visual injury at the Beaumont location during the 2008 growing season was only observed at the first visual assessment in one plot. Injury was minimal and received a visual injury rating of 5% clomazone injury 13 days after the last EPOST application. In all other plots clomazone injury was not detectable. At the time of the second visual assessment, no clomazone injury was observed in any plot. Clomazone injury was not observed for the remainder of the 2008 growing season at the Beaumont location. Data from the first visual assessment in 2008 was homogeneous with the first visual injury assessment in the 2009 Beaumont study and was combined for analysis (Table 2). Treatments receiving the highest rate of 0.56 kg ha^{-1} at the PRE timing had the numerically highest visual injury means. The treatment receiving only the PRE treatment of clomazone had the numerically lowest visual injury rating mean other than the control. No significant interaction was observed between the three different seeding rates. Visual injury persisted to the second visual injury timing in 2009 and was analyzed independently from 2008, when visual injury had already dissipated (Table 3).

Table 1. Multiple assessment *P* values for visual injury assessments and yield from

Source	Pr > F for parameters			
	Visual injury[a]			
	1st	2nd	3rd	Yield
Year (Y)	< .0001	< .0001	< .0001	0.0005
Block (Year)	< .0001	< .0001	< .0001	< .0001
Location (Loc)	< .0001	< .0001	< .0001	< .0001
Block (Location)	0.9421	< .0001	< .0001	0.0038
Clomazone (C)	< .0001	< .0001	< .0001	< .0001
Seeding Rate (S)	0.3074	0.0377	0.0019	0.2185
Y * Loc	< .0001	< .0001	< .0001	0.7169
Y * C	< .0001	< .0001	< .0001	0.0686
Y * S	0.6352	0.0377	0.0019	0.2574
Loc * C	< .0001	0.0405	< .0001	0.0253
Loc * S	0.6616	0.5992	0.0019	0.9359
C * S	0.9877	0.8207	0.6060	0.9304
Y * Loc * C	< .0001	0.0405	< .0001	0.0119
Y * Loc * S	0.7409	0.5992	0.0019	0.1011
Y * C * S	0.9992	0.8207	0.6060	0.9667
Loc * C * S	0.9216	0.9795	0.6060	0.9901
Y * Loc * C * S	0.9793	0.9795	0.6060	0.9924

[a] Represents the 1st, 2nd, and 3rd visual injury assessment. Assessments were taken at Beaumont 14, 26 and 34 days after application, respectively. Assessments were taken at Eagle Lake 16, 29 and 34 days after application.

Table 2. Mean injury within herbicide treatments at the time of the first visual injury assessment at the Beaumont, TX location in the 2008 and 2009 growing season.

Herbicide Treatment[a]	Herbicide Rate (kg ha^{-1})	Total Clomazone Applied (kg ha^{-1})	Application Timing	Mean Injury[b]
P + Q	3.36 + 0.56	0	EPOST + EPOST	0 e
C + C	0.34 + 0.42	0.76	PRE + EPOST	1.7 cd
C + C	0.34 + 0.56	0.90	PRE + EPOST	2 bc
C + C	0.42 + 0.42	0.84	PRE + EPOST	2.3 abc
C + C	0.42 + 0.56	0.98	PRE + EPOST	2.9 abc
C + C	0.56 + 0.34	0.90	PRE + EPOST	3.3 ab
C + C	0.56 + 0.42	0.98	PRE + EPOST	3.8 a
C	0.56	0.56	PRE	0.8 de

[a] Abbreviations: P, propanil; Q, quinclorac; C, clomazone; EPOST, early postemergence; PRE, preemergence.
[b] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Table 3. Mean visual injury ratings at the second and third visual assessment at the Beaumont, TX location in 2009.

Herbicide Treatment[a]	Herbicide Rate (kg ha^{-1})	Total Clomazone Applied (kg ha^{-1})	Application Timing	Mean Injury 26 DAT	Mean Injury 34 DAT
P + Q	3.36 + 0.56	0	EPOST + EPOST	0 d[b]	0[c]
C + C	0.34 + 0.42	0.76	PRE + EPOST	3 bc	0
C + C	0.34 + 0.56	0.90	PRE + EPOST	4 abc	0
C + C	0.42 + 0.42	0.84	PRE + EPOST	5 ab	0
C + C	0.42 + 0.56	0.98	PRE + EPOST	6 ab	0
C + C	0.56 + 0.34	0.90	PRE + EPOST	8 a	0
C + C	056 + 0.42	0.98	PRE + EPOST	8 a	0
C	0.56	0.56	PRE	2 cd	0

[a] Abbreviations: P, propanil; Q, quinclorac; C, clomazone; EPOST, early postemergence; PRE, preemergence.
[b] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).
[c] Means were not statistically different according to F-test at $P \leq 0.05$.

Plots receiving the highest rates of clomazone applied at the PRE timing showed the greatest injury at the second visual assessment rating. By the third assessment, visual injury was not detectable and clomazone injury had dissipated.

Yield collected at the conclusion of the season was homogeneous with the yield data obtained in the March 2009 study at Beaumont and both, 2008 and 2009 March studies conducted at Eagle Lake. Yield data from both locations and years were combined for analysis. Treatments receiving the two highest total rates of clomazone, from both PRE and EPOST applications, yielded higher than treatments receiving lower rates of total clomazone applied (Table 4). The highest yielding treatment received the highest total rate of clomazone. No difference was observed in yield among any of the three different seeding rates (Table 5).

In the 2008 growing season near Eagle Lake, the first visual assessment was conducted 11 days after the last EPOST application. Visual injury was observed as high as 60% in some plots; however, the injury had dissipated and was no longer visually detectable at the second visual assessment 29 days after the EPOST application. Visual injury ratings from the first visual assessment in 2008 were homogeneous to the initial visual injury ratings observed in the 2009 season at Eagle Lake and were combined for analysis (Table 6). The highest mean visual injury was observed for treatments receiving the three highest rates of clomazone applied, 0.67, 0.70 and 0.76 kg ha^{-1}. These treatments were not statistically different. The lowest mean herbicide injury was observed in the weed-free control treatment that received propanil and quinclorac without the addition of any clomazone.

Table 4. Mean yield from different herbicide treatments at the Beaumont and Eagle Lake location in 2008 and 2009 at the March planting dates.

Herbicide Treatment[a]	Herbicide Rate (kg ha^{-1})	Total Clomazone Applied (kg ha^{-1})	Application Timing	Yield (kg ha^{-1})
P + Q	3.36 + 0.56[b]	0[b]	EPOST + EPOST	6707 b[d]
	3.36 + 0.56[c]	0[c]		
C + C	0.28 + 0.34[b]	0.62[b]	PRE + EPOST	6292 bc
	0.34 + 0.42[c]	0.76[c]		
C + C	0.28 + 0.42[b]	0.70[b]	PRE + EPOST	7178 a
	0.34 + 0.56[c]	0.90[c]		
C + C	0.34 + 0.34[b]	0.67[b]	PRE + EPOST	7096 ab
	0.42 + 0.42[c]	0.84[c]		
C + C	0.34 + 0.42[b]	0.76[b]	PRE + EPOST	7439 a
	0.42 + 0.56[c]	0.98[c]		
C + C	0.42 + 0.28[b]	0.70[b]	PRE + EPOST	7368 a
	0.56 + 0.34[c]	0.90[c]		
C + C	0.42 + 0.34[b]	0.76[b]	PRE + EPOST	7286 a
	0.56 + 0.42[c]	0.98[c]		
C	0.42[b]	0.42[b]	PRE	6630 bc
	0.56[c]	0.56[c]		

[a] Abbreviations: P, propanil; Q, quinclorac; C, clomazone; EPOST, early postemergence; PRE, preemergence.
[b] Rates of clomazone applied at the Eagle Lake, TX location.
[c] Rates of clomazone applied at the Beaumont, TX location.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Table 5. Mean yield harvested from three different seeding rates of hybrid rice for March planting dates in both study years, 2008 and 2009, and both locations, Beaumont and Eagle Lake**.**

Planting Rate (kg ha^{-1})	Yield (kg ha^{-1})[a]
28	6889
39	6962
50	7157

[a] Means were not significantly different according to F-test at $P \leq 0.05$.

Table 6. Mean injury within herbicide treatments at the time of the first visual injury assessment at the Beaumont, TX location in the 2008 and 2009 growing season.

Herbicide Treatment[a]	Herbicide Rate ($kg\ ha^{-1}$)	Total Clomazone Applied ($kg\ ha^{-1}$)	Application Timing	Mean Injury[b]
P + Q	3.36 + 0.56	0	EPOST + EPOST	0 d
C + C	0.28 + 0.34	0.62	PRE + EPOST	38 b
C + C	0.28 + 0.42	0.70	PRE + EPOST	49 a
C + C	0.34 + 0.34	0.67	PRE + EPOST	48 a
C + C	0.34 + 0.42	0.76	PRE + EPOST	55 a
C + C	0.42 + 0.28	0.70	PRE + EPOST	48 a
C + C	0.42 + 0.34	0.76	PRE + EPOST	54 a
C	0.42	0.42	PRE	33 c

[a] Abbreviations: P, propanil; Q, quinclorac; C, clomazone; EPOST, early postemergence; PRE, preemergence.
[b] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Initial injury ratings as high as 90% were observed in some plots in 2009 at Eagle Lake. Clomazone injury was observed at the second and third visual assessment, or 29 and 34 days after the EPOST application, respectively. Injury was not observed at the fourth and final visual assessment 50 days after the last application. At the second visual injury assessment some plots received visual injury ratings at 35% and the highest observed injury within a single plot at the third visual assessment was 40%. The highest mean injury was observed in treatments receiving the higher total rates of clomazone applied (Table 7). This was observed in both, second and third visual assessments.

April Planting Date. Similar to the March planting date, following an initial ANOVA and verification from Hartley's Test to determine if the data from the April planting date was suitable for combination, a combined ANOVA was performed (Table 8). It was determined that yield from both locations and years could be combined for analysis, and the first visual assessment data from 2008 and 2009 at the Eagle Lake location could be combined. Data from test parameters not homogeneous were analyzed independently.

Visual injury at the Beaumont location in both, 2008 and 2009 growing seasons was not observed in any plot. Organic carbon content of 1.2% and a high percentage of clay minerals, along with warmer temperatures at the April planting may have been related to the lack of visual clomazone injury observed at the Beaumont location. Yield from both years at this location were combined with both years at the Eagle Lake location following the test for homogeneity. Yield was greatest in treatments receiving the highest rates of total clomazone applied from both applications (Table 9).

Table 7. Mean visual injury ratings at the second and third visual assessment at the Eagle Lake, TX location in the March planting date of 2009.

Herbicide Treatment[a]	Herbicide Rate ($kg\ ha^{-1}$)	Total Clomazone Applied ($kg\ ha^{-1}$)	Application Timing	Mean Injury 29 DAT	Mean Injury 34 DAT
P + Q	3.36 + 0.56	0	EPOST + EPOST	0 c[b]	0 d[b]
C + C	0.28 + 0.34	0.62	PRE + EPOST	9 b	9 c
C + C	0.28 + 0.42	0.70	PRE + EPOST	14 ab	14 abc
C + C	0.34 + 0.34	0.67	PRE + EPOST	14 ab	12 abc
C + C	0.34 + 0.42	0.76	PRE + EPOST	18 a	17 ab
C + C	0.42 + 0.28	0.70	PRE + EPOST	16 ab	16 ab
C + C	0.42 + 0.34	0.76	PRE + EPOST	18 a	18 a
C	0.42	0.42	PRE	9 b	11 bc

[a] Abbreviations: P, propanil; Q, quinclorac; C, clomazone; EPOST, early postemergence; PRE, preemergence.
[b] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Table 8. Multiple assessment *P* values for visual injury assessments and yield from clomazone application and three different seeding rates at the April planting date.

Source	Pr > F for parameters		
	Visual injury[a]		
	1st	2nd	Yield
Year (Y)	0.0004	< .0001	0.0050
Block (Year)	0.1335	0.1661	< .0001
Location (Loc)	< .0001	< .0001	0.0001
Block (Location)	0.0158	0.1661	< .0001
Clomazone (C)	< .0001	0.0232	< .0001
Seeding Rate (S)	< .0001	< .0001	0.0083
Y * Loc	0.0013	< .0001	< .0001
Y * C	0.0017	0.0232	< .0001
Y * S	< .0001	< .0001	0.0561
Loc * C	< .0001	0.0232	0.0060
Loc * S	0.0001	< .0001	0.9842
C * S	0.9383	0.9955	0.9968
Y * Loc * C	0.0017	0.0232	< .0001
Y * Loc * S	< .0001	< .0001	0.2764
Y * C * S	0.9875	0.9955	0.9958
Loc * C * S	0.8706	0.9955	0.0625
Y * Loc * C * S	0.9732	0.9955	0.9131

[a] Represents the 1^{st} and 2nd visual injury assessment.

Table 9. Mean yield from different herbicide treatments at the Beaumont and Eagle Lake location in 2008 and 2009 at the April planting dates.

Herbicide Treatment[a]	Herbicide Rate (kg ha^{-1})	Total Clomazone Applied (kg ha^{-1})	Application Timing	Yield (kg ha^{-1})
P + Q	3.36 + 0.56[b]	0[b]	EPOST + EPOST	7446 c[d]
	3.36 + 0.56[c]	0[c]		
C + C	0.28 + 0.34[b]	0.62[b]	PRE + EPOST	7866 bc
	0.34 + 0.42[c]	0.76[c]		
C + C	0.28 + 0.42[b]	0.70[b]	PRE + EPOST	8086 ab
	0.34 + 0.56[c]	0.90[c]		
C + C	0.34 + 0.34[b]	0.67[b]	PRE + EPOST	8503 a
	0.42 + 0.42[c]	0.84[c]		
C + C	0.34 + 0.42[b]	0.76[b]	PRE + EPOST	8111 ab
	0.42 + 0.56[c]	0.98[c]		
C + C	0.42 + 0.28[b]	0.70[b]	PRE + EPOST	8497 a
	0.56 + 0.34[c]	0.90[c]		
C + C	0.42 + 0.34[b]	0.76[b]	PRE + EPOST	8243 ab
	0.56 + 0.42[c]	0.98[c]		
C	0.42[b]	0.42[b]	PRE	8038 b
	0.56[c]	0.56[c]		

[a] Abbreviations: P, propanil; Q, quinclorac; C, clomazone; EPOST, early postemergence; PRE, preemergence.
[b] Rates of clomazone applied at the Eagle Lake, TX location.
[c] Rates of clomazone applied at the Beaumont, TX location.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

The lowest mean yield was observed in the treatment receiving propanil and quinclorac with no clomazone, most likely as a result of increased grass-weed pressure. An interaction was observed in yield combined within seeding rate. The lowest planting density of 28 kg ha^{-1} yielded lower than the highest planting density of 50 kg ha^{-1} (Table 10). This may have been related to a reduction in the number of rice plants per unit area, resulting in the observed decrease in yield between planting densities.

At the Eagle Lake location, initial visual injury ratings from the April planting date in 2008 and 2009 were homogeneous. As a result, the years were combined for analysis (Table 11). The first visual assessment ratings occurred 11 and 18 days after the final EPOST application in 2008 and 2009, respectively. Mean injury was observed at less than 10% in all treatments. The greatest mean clomazone injury was observed in treatments receiving the highest rates of total clomazone applied. The treatments consisting of the lowest rate of clomazone applied in a split application, and one application PRE, had less mean herbicide injury than other treatments receiving clomazone. The treatment with the lowest numerical mean for herbicide injury was the treatment receiving only propanil and quinclorac.

In the 2008 April planting date at Eagle Lake, injury was still detectable at the time of the second visual assessment 20 days after the last application occurred (Table 12). The highest visual injury assessment observed in a single plot was 15%. The highest mean injury was observed in treatments receiving the highest rates of total clomazone applied. In 2009 however, injury had dissipated and was no longer detectable at the time of the second visual assessment 28 days after the last herbicide application.

Table 10. Mean yield harvested from three different seeding rates of hybrid rice in April plantings of both study years, 2008 and 2009 at both locations, Beaumont and Eagle Lake.

Planting Rate (kg ha^{-1})	Yield (kg ha^{-1})
28	7934 b[a]
39	8123 a
50	8235 a

[a] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Table 11. Mean injury within herbicide treatments at the time of the first visual injury assessment at the Eagle Lake, TX location at the April planting in 2008 and 2009.

Herbicide Treatment[a]	Herbicide Rate (kg ha^{-1})	Total Clomazone Applied (kg ha^{-1})	Application Timing	Mean Injury
P + Q	3.36 + 0.56	0	EPOST + EPOST	3 d[b]
C + C	0.28 + 0.34	0.62	PRE + EPOST	4 cd
C + C	0.28 + 0.42	0.70	PRE + EPOST	6 abc
C + C	0.34 + 0.34	0.67	PRE + EPOST	6 abc
C + C	0.34 + 0.42	0.76	PRE + EPOST	7 abc
C + C	0.42 + 0.28	0.70	PRE + EPOST	8 ab
C + C	0.42 + 0.34	0.76	PRE +EPOST	9 a
C	0.42	0.42	PRE	5 bc

[a] Abbreviations: P, propanil; Q, quinclorac; C, clomazone; EPOST, early postemergence; PRE, preemergence.
[b] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Table 12. Mean visual injury ratings at the second visual assessment at the Eagle Lake, TX location in the April planting date of 2009.

Herbicide Treatment[a]	Herbicide Rate (kg ha^{-1})	Total Clomazone Applied (kg ha^{-1})	Application Timing	Mean Injury
P + Q	3.36 + 0.56	0	EPOST + EPOST	6 ab[b]
C + C	0.28 + 0.34	0.62	PRE + EPOST	4 b
C + C	0.28 + 0.42	0.70	PRE + EPOST	6 ab
C + C	0.34 + 0.34	0.67	PRE + EPOST	8 ab
C + C	0.34 + 0.42	0.76	PRE + EPOST	7 ab
C + C	0.42 + 0.28	0.70	PRE + EPOST	9 ab
C + C	0.42 + 0.34	0.76	PRE +EPOST	10 a
C	0.42	0.42	PRE	6 ab

[a] Abbreviations: P, propanil; Q, quinclorac; C, clomazone; EPOST, early postemergence; PRE, preemergence.

[b] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Increased clomazone injury was observed in the March plantings at both locations in 2008 and 2009. Cooler environmental conditions at this early planting date may have increased the severity of clomazone injury at both locations. In both years, herbicide injury observed at both locations dissipated and did not translate into a yield reduction when compared to an alternative weed control program recommended by Texas Rice Production Guidelines (McCauley and Senseman 2012). Less clomazone injury was observed in the April planting date at both locations and did not translate into a yield reduction when compared to an alternative weed control program. Clomazone injury did not increase as seeding rate decreased in any year or location. Yield decreased at the lowest seeding density in the combined analysis of 2008 and 2009 at both locations. This observation was most likely the result of a reduced number of plants per unit area that translated into a reduction in grain yield.

CHAPTER III

FERTILITY-BASED HERBICIDE INJURY RECOVERY FROM CLOMAZONE HERBICIDE IN HYBRID RICE

Introduction

While registered for use in rice production in 2001, clomazone was not initially labeled for use in coarse-textured soils that primarily occur in the western production areas of the Texas rice belt. Clomazone was registered for use in May 2006 on these coarse-textured soils with low organic matter content (≤ 1%) occurring in the rice production region west of Houston, Texas (Willingham et al. 2008). Research conducted previous to clomazone registration in 2006 concluded that clomazone is safe to use for rice production within these areas, even if injury from the herbicide is present (O'Barr et al. 2007). Recommended rates for clomazone use in coarse-textured soils is lower than recommended rates for heavier soils with increased organic matter content.

Texas Rice Production Guidelines recommend cultural practices to rice producers including the addition of fertility amendments and irrigation timings depending on the type of production system the producer is using. Since clomazone is applied PRE or EPOST, the application is executed at a time when several production practices have not yet occurred. Field studies in the past have not analyzed what effects, if any, regular production practices might have on early season clomazone injury. Typically after clomazone application timing at the PRE or EPOST growth stage, additional herbicide application, fertilizer placement, and flush or permanent flood irrigation is conducted.

One important component to rice production is proper rate and timing of mid- to late-season fertility applications. Texas Rice Production Guidelines recommend all phosphorus and potassium amendments, if needed, be applied before planting and no later than the three-leaf growth stage. Three different N fertilizer timings are recommended for March and April plantings, and two for May plantings. For March plantings, recommendations state that 20 to 25% of N fertilizers should be applied at a pre-plant timing, 35 to 40% just prior to the permanent flood establishment, and 40% at the panicle differentiation growth stage (Dou and Tarpley 2012). Guidelines suggest rice planted in April receive N fertilizers at the same three timings; however, it is recommended that one-third of the total N required should be applied at each event. For rice planted in May, guidelines recommend that two-thirds of all N fertilizers be applied at a pre-plant timing and the remaining one-third be applied at the panicle differentiation growth stage (Dou and Tarpley 2012). These recommendations serve the purpose of facilitating more efficient use of N fertilizers by allowing for increased rice plant uptake and to prevent unnecessary loss of N from the flooded rice production system through volatilization and other processes.

The addition of essential plant nutrients can increase overall plant vigor and yield. Past research suggests that early season clomazone injury does not affect rice yield, and that improved control of grassy weeds may actually increase rice yield through decreased competition for plant nutrients and sunlight (Webster et al. 1999; Zhang et al. 2004). Past research has not analyzed effects fertility amendments may have on rice plants injured by clomazone herbicide. Since guidelines suggest additional fertility applications after the growth timing when clomazone should be applied, remediation from fertility amendments used in the production system would incur little or no additional cost to the producer. Different forms of plant fertilizers, rates, timings, or combinations of the aforementioned may increase a rice plant's capacity to recover from clomazone injury at a faster rate. Forms of plant fertilizers currently used in rice production systems are essential to the minimization of additional cost for clomazone remediation. This study focused on two forms of N fertilizers, urea and ammonium sulfate, and two micronutrients, iron sulfate and magnesium sulfate. Different rates applied at different timings, and combinations of the four amendments were assessed for activity related to clomazone herbicide remediation.

Materials and Methods

Field Study. Field studies were conducted in 2010 at the Texas AgriLife Research station near Eagle Lake, TX and a satellite research facility near Ganado, TX. The study near Eagle Lake was planted into a Nada fine sandy loam with 61% sand, 31% silt, 8% clay, 0.7% organic matter, and a pH of 6.1. The study near Ganado was planted into an Edna fine sandy loam with 55% sand, 33% silt, 12% clay, 0.8% organic matter, and a pH of 6.1. Field locations at both study sites were in a rice-fallow rotation system. At Eagle Lake rice was planted every three years with fallow periods between. The location near Ganado remained fallow for at least three years before planting occurred. Before the study was established, a seedbed with adequate slope for flood irrigation practices was prepared following cultivation.

At the Eagle Lake location, “XL 723” hybrid rice was drill seeded on March 31, 2010. Near Ganado the same hybrid, “XL 723” was drill seeded on April 6, 2010. At both locations the planting rate was 39 kg ha^{-1}. The experimental design was a randomized complete block design with four replications. Plot size at both locations was 1.5 m wide and 4.9 m long. Plots consisted of 7 rows of hybrid rice spaced 19 cm apart with each plot separated by an alley approximately 0.3 m wide. Rice plant emergence occurred April 7 at the Eagle Lake location and April 17 near Ganado.

Before planting occurred, phosphorus and potassium fertilizers were applied at both field locations. At Eagle Lake and Ganado, 56 kg ha^{-1} of P_2O_5 in the form of triple super phosphate and 56 kg ha^{-1} of K_2O in the form of potassium chloride were applied following soil tests. A cultipacker implement was used to smooth the seedbed following planting and clomazone herbicide was applied PRE. Two individual experiments comprised the overall scope of this research study. In the first experiment, clomazone was applied in treatments of linearly increasing concentrations to produce a standard curve of clomazone injury. The clomazone rates applied as individual treatments for this experiment were 0.11, 0.22, 0.34, 0.45, 0.56, and 0.67 kg ha^{-1}. The control for this experiment included plots receiving no herbicide application. The second experiment received clomazone applied uniformly across the entire plot area at 0.45 kg ha^{-1} to induce clomazone injury and assess injury recovery from fertility amendments.

Following the initial PRE application, clomazone injury was minimal and visually undetectable in some plots at both locations. A second application was made at each location at the EPOST timing. Rates for the second, EPOST application were the same rates applied in the initial PRE application. For standard curve experiments, the total amount of clomazone applied from both applications was 0.22, 0.44, 0.68, 0.9, 1.12, and 1.34 kg ha^{-1}. The total rate of clomazone applied to experiments assessing injury remediation from both PRE and EPOST applications was 0.9 kg ha^{-1}. Following the EPOST application, rice plants showed adequate clomazone injury to proceed to visual assessment and fertility application. PRE applications were made March 31 near Eagle Lake and April 6 near Ganado. EPOST applications were applied May 5 at both, the Eagle Lake and Ganado locations. All herbicide treatments were delivered with a spray boom containing three flat-fan nozzles (Teejet XR 11002, Spraying Systems Co,. Wheaton, IL) spaced 50 cm apart. The boom was attached to a 3-liter spray solution reservoir pressurized with a CO_2 backpack sprayer adjusted to deliver 140 L ha^{-1} of spray solution at 172 kPa.

Following the EPOST applications, visual injury ratings, plant height measurements and tissue samples were collected for later analysis of chlorophyll content in the laboratory. Visual injury ratings were assigned to each plot on a percentage basis. A visual injury rating of 0% indicated that no visual injury symptoms were detected in that plot. A visual injury rating of 50% indicated that approximately half of all above-ground rice plant tissue showed visual injury symptoms characteristic of clomazone. An injury rating of 100% indicated that total plant death had occurred in the plot. Plant height was recorded with a hand-held metric ruler.

At the time of first visual assessment, rice plants were at the 3- to 4 leaf growth stage. Following this initial visual assessment, fertility treatments consisting of different fertilizers, rates, timings, and combinations of each were applied (Table 13). Initial rice tissue samples were also collected during this event. Three other assessment events followed with visual injury ratings, tissue samples and plant height measurements collected. At the conclusion of the field study, fields were drained and rice grain was harvested when moisture content was approximately 20%. Four rows of each plot were harvested using a mechanical harvester. Moisture content and grain weight were collected using an electronic scale and moisture meter, and grain weight was adjusted to 12% moisture content and converted to kg ha^{-1}. All data from the standard curve experiment including visual injury ratings, height measurements, chlorophyll content determined in the laboratory experiment and yield were subjected to regression analysis using SAS computer software (SAS 2011). All data collected in the clomazone injury recovery experiment was subjected to ANOVA using the GLM procedure in SAS software. Means for significant effects were separated using Tukey's Test ($p \leq 0.05$).

Laboratory Study. Tissue samples collected in the field at each visual assessment event were subject to analysis in the laboratory for chlorophyll content. At each visual assessment, a representative sample of above-ground rice tissue was collected from each plot. Samples were obtained by severing with scissors a randomly selected 30-cm long strip of rice plants in the same row. The tissue was then placed in a plastic bag marked with the corresponding plot number. Samples were transported back to the laboratory and frozen for later analysis.

The laboratory method used for the determination of chlorophyll content was similar to the method used by Lee et al. (2004). Rice tissue was was brought to room

Table 13. Fertility treatments, rates and timings applied in the clomazone injury recovery experiment near Eagle Lake and Ganado, TX[a].

Fertility Amendments	Formulated Fertilizer Applied	Nitrogen Applied	Application Timing
Ammonium Sulfate (AS)	320 kg ha^{-1}	67 kg ha^{-1}	LPOST
(AS)	640 kg ha^{-1}	134 kg ha^{-1}	LPOST
Urea	146 kg ha^{-1}	67 kg ha^{-1}	LPOST
Urea	292 kg ha^{-1}	134 kg ha^{-1}	LPOST
Urea Urea	110 kg ha^{-1} 146 kg ha^{-1}	50 kg ha^{-1} 67 kg ha^{-1}	LPOST PREFLOOD
Urea Urea	219 kg ha^{-1} 146 kg ha^{-1}	101 kg ha^{-1} 67 kg ha^{-1}	LPOST PREFLOOD
Iron Sulfate (IS)	1% w/w	0 kg ha^{-1}	LPOST
AS IS	320 kg ha^{-1} 1% w/w	67 kg ha^{-1} 0 kg ha^{-1}	LPOST LPOST
AS IS	640 kg ha^{-1} 1% w/w	134 kg ha^{-1} 0 kg ha^{-1}	LPOST LPOST
Urea IS	292 kg ha^{-1} 1% w/w	134 kg ha^{-1} 0 kg ha^{-1}	LPOST LPOST
Urea IS Urea	219 kg ha^{-1} 1% w/w 146 kg ha^{-1}	101 kg ha^{-1} 0 kg ha^{-1} 67 kg ha^{-1}	LPOST LPOST PREFLOOD
Magnesium Sulfate (MS)	0.5% w/w	0 kg ha^{-1}	LPOST

Table 13. Continued.

Fertility Amendments	Formulated Fertilizer Applied	Nitrogen Applied	Application Timing
IS	1 % w/w	0 kg ha^{-1}	LPOST
MS	0.5 % w/w	0 kg ha^{-1}	LPOST

[a]Abbreviations: LPOST, late postemergence.
[b]LPOST application timing occurs at the 4- to 6 leaf growth stage. PREFLOOD application timing occurs immediately before the permanent flood is established.

temperature before sample preparation began. Initial preparation included removing a representative sample from the bag and recording the mass with an electronic scale. Weights were recorded for determination of chlorophyll content on a w/w basis. The amount of tissue weighed was then placed in glass test tubes. Seven (7) mLs of dimethyl sulfoxide (DMSO) was added to each test tube and placed in a temperature bath held at 65 C for chlorophyll extraction. Tubes remained in the temperature bath for 1 h and were then vortexed at 15-min intervals. The solution from each tube was decanted into a graduated test tube and brought to a 10-mL volume with DMSO. The sample was then vortexed again to homogenize the solution. A 1-mL aliquot of each sample was then transferred to a cuvette for analysis in a Beckman DU530 UV-visible spectrophotometer. Absorbance readings for chlorophyll *a* and chlorophyll *b* were taken at 663 nm and 645 nm, respectively, against a DMSO blank. If readings were greater than 0.7, the samples were diluted with a 90% DMSO-10% water solution. Some samples were diluted as much as 90% to achieve absorbance values below 0.7.

Chlorophyll was determined using Arnon's equation (1949), where total chlorophyll$_{(a+b)} = 8.02A_{663} + 20.20b_{645}$. In this equation, A_{663} is the absorbance reading for chlorophyll *a* at 663 nm and chlorophyll *b* at 645 nm (Arnon 1949). Once the absorbance readings were recorded, they were then converted to mg of chlorophyll per g of fresh weight for each sample analyzed. Data collected from the laboratory experiment was then analyzed statistically. Chlorophyll content from the standard curve experiment was included in the regression analysis with data from the field study. Chlorophyll values from the herbicide recovery experiment were included in the ANOVA analysis with other data parameters from the field experiment.

Results and Discussion

Eagle Lake. *Standard curve*. The test parameters analyzed in this experiment included visual injury assessment, plant height, chlorophyll content and yield. From the visual injury data collected, the first timing at 47 DAP produced a significant regression model with an R^2 value of 0.67 (Figure 1). Visual injury was not detectable at the lower rates and the lowest rate of clomazone where injury symptoms were detected was 0.9 kg ha^{-1}. All plots receiving the 1.12 kg ha^{-1} rate of clomazone were assigned an injury rate of 5%. The highest injury rating assigned to any one plot was 10% and this occurred only in the treatment receiving the highest rate of clomazone at 1.34 kg ha^{-1}. At the time of the second visual assessment 68 DAP, clomazone injury was detected in only one plot at 10%. All other plots showed no clomazone injury symptoms.

Plant height measurements were recorded at the three different timings, 68, 76 and 96 DAP. Regression analysis for plant height did not produce a significant model for any plant height data at any timing. At the conclusion of the study mean plant height was 97 cm tall in all plots. Data obtained from the chlorophyll content analysis in the laboratory was also analyzed by regression, however, a significant model was not produced. Chlorophyll content increased in most plots at the later sampling dates but no statistical trend existed in data obtained within each sampling date.

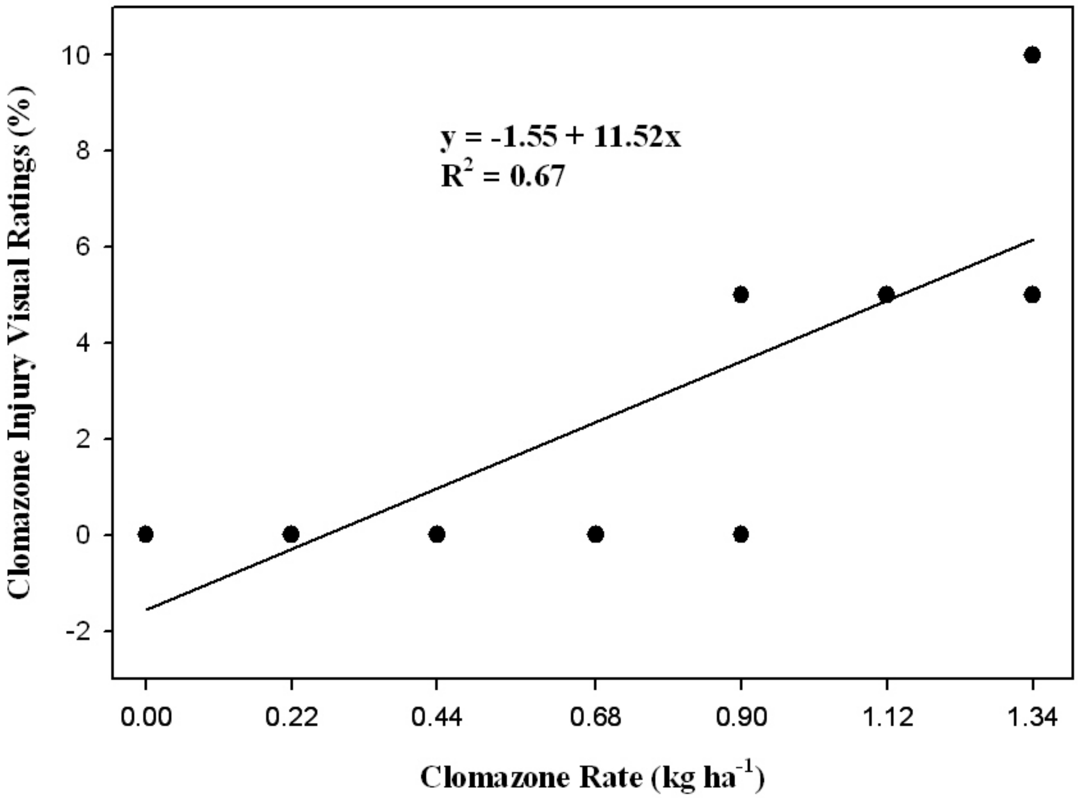

Figure 1. Standard curve experiment regression analysis of visual injury 46 DAP at Eagle Lake, TX.

Yield data collected at the conclusion of the study produced a significant regression model with an R^2 of 0.49 (Figure 2). Plots receiving higher rates of clomazone yielded more rice grain than those receiving the lower rates, probably a result of decreased competition from enhanced weed control. The lowest mean yield was observed in plots receiving no clomazone and the highest mean yield was observed in plots receiving the highest rate of clomazone.

Ganado. *Standard curve.* Test parameters at Ganado were the same parameters evaluated at Eagle Lake and included visual injury assessment, plant height, chlorophyll content and yield. All data were subject to regression analysis and statistically significant regression models were obtained for all visual injury assessments and plant height measurements. Yield and lab data from the chlorophyll extraction procedure to determine chlorophyll content did not produce a significant regression model.

Visual injury ratings at the first visual assessment 46 DAP produced a model with an R^2 of 0.70 (Figure 3).Visual injury ratings as high as 45% were observed in plots receiving the highest rate of clomazone at 1.34 kg ha^{-1}. The lowest visual injury ratings were observed in plots receiving no or low rates of clomazone. One plot receiving no clomazone was assigned a visual injury rating of 5%, most likely as a result of herbicide drift at the time of application. Visual injury ratings at the second visual assessment 68 DAP produced a model with an R^2 of 0.36 (Figure 4). No visual injury was detected in plots receiving 0.68 kg ha^{-1} of clomazone and lower. Clomazone injury symptoms were still detectable in plots receiving 0.9 kg ha^{-1} and higher. The highest visual injury rating was assigned to a plot receiving the highest rate of clomazone, 1.34 kg ha^{-1}. At the time

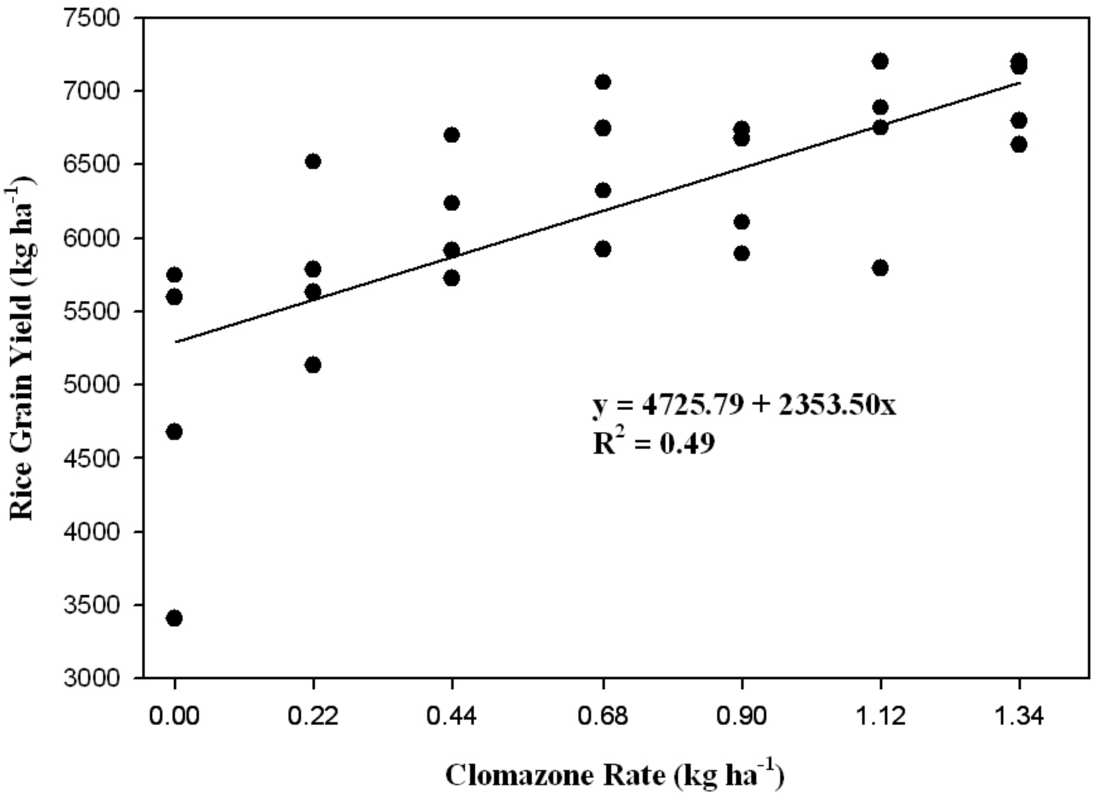

Figure 2. Standard curve experiment regression analysis of yield data near Eagle Lake, TX.

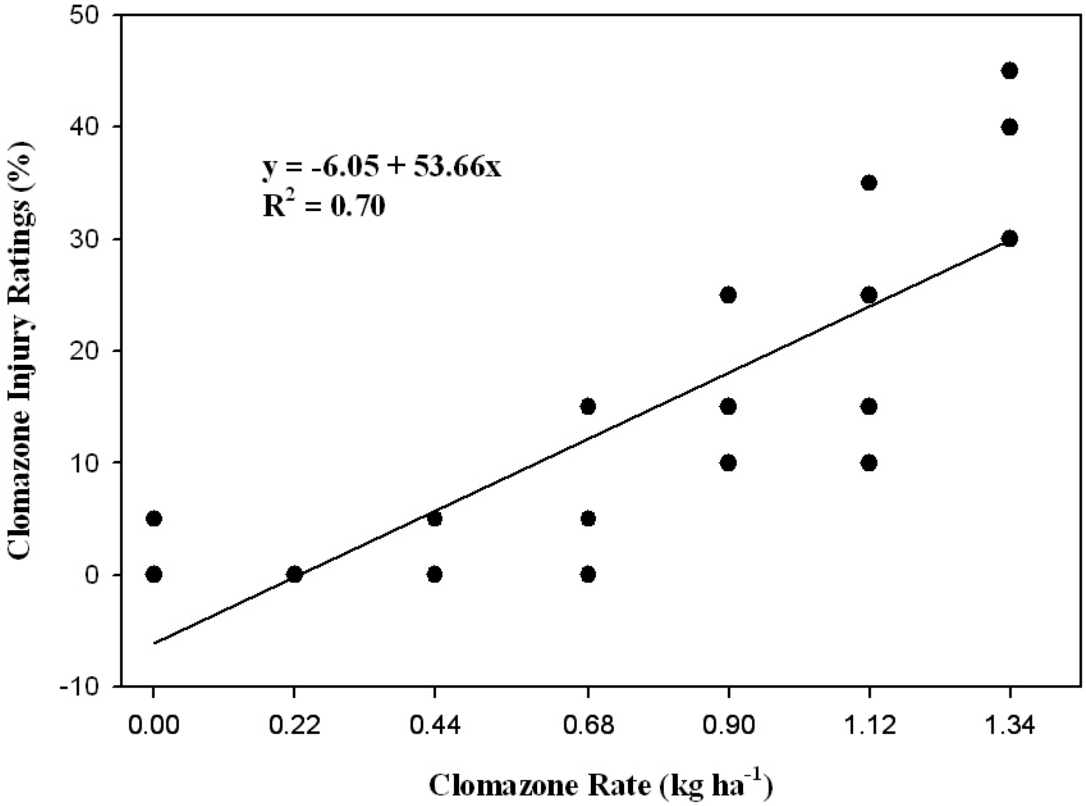

Figure 3. Standard curve experiment regression analysis of visual injury 41 DAP at Ganado, TX.

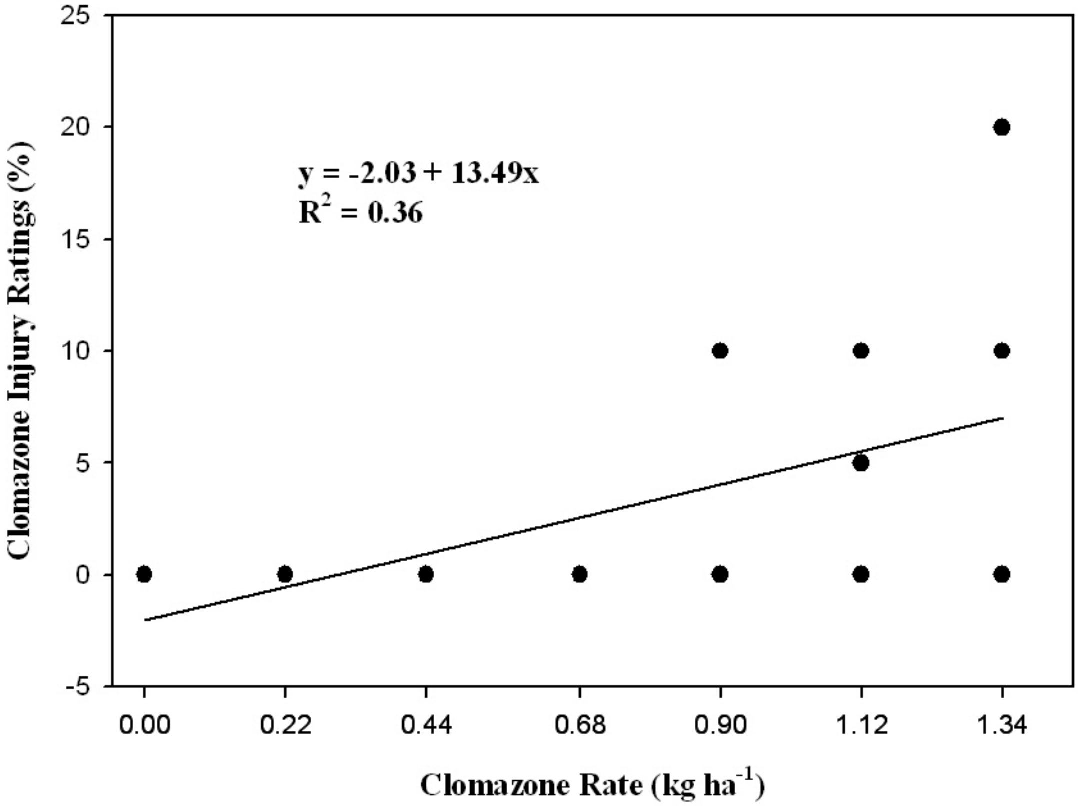

Figure 4. Standard curve experiment regression analysis of visual injury 62 DAP at Ganado, TX.

of the third visual assessment 76 DAP, clomazone injury was no longer detectable in any plot.

Plant height measurement data collected at the time of the second visual assessment timing produced a significant regression model with an R^2 of 0.27 (Figure 5). The highest plant height recorded at this time was 89 cm and was observed in a plot receiving 0.68 kg ha^{-1} of clomazone. Mean plant height decreased at rates higher and equal to 0.9 kg ha^{-1}, most likely a result of clomazone injury. The lowest recorded plant height, 74 cm, occurred in plots receiving the two highest rates of clomazone applied, 1.12 and 1.34 kg ha^{-1}.

Plant height was assessed at the third visual assessment event, 71 DAP, and measurements were recorded. Data from this assessment produced a regression model with an R^2 of 0.34 (Figure 6). The lowest recorded values for plant height at this time were 89 cm and the greatest plant heights observed were 94 cm. All rice plants in plots receiving the highest rate of clomazone exhibited the lowest plant height observed at this time, 89 cm, and may have been a result of persistent clomazone injury. The range of observed measurements at 71 DAP decreased compared to 62 DAP. At the assessment done 96 DAP, all rice plants measured the same in all plots at 127 cm, suggesting that clomazone applied at rates higher than recommended by the label affected early season plant growth but eventually dissipated as the plants approached physiological maturity.

Eagle Lake. *Clomazone injury recovery.* Test parameters for the injury recovery study included visual injury assessment, plant height, chlorophyll content and yield.

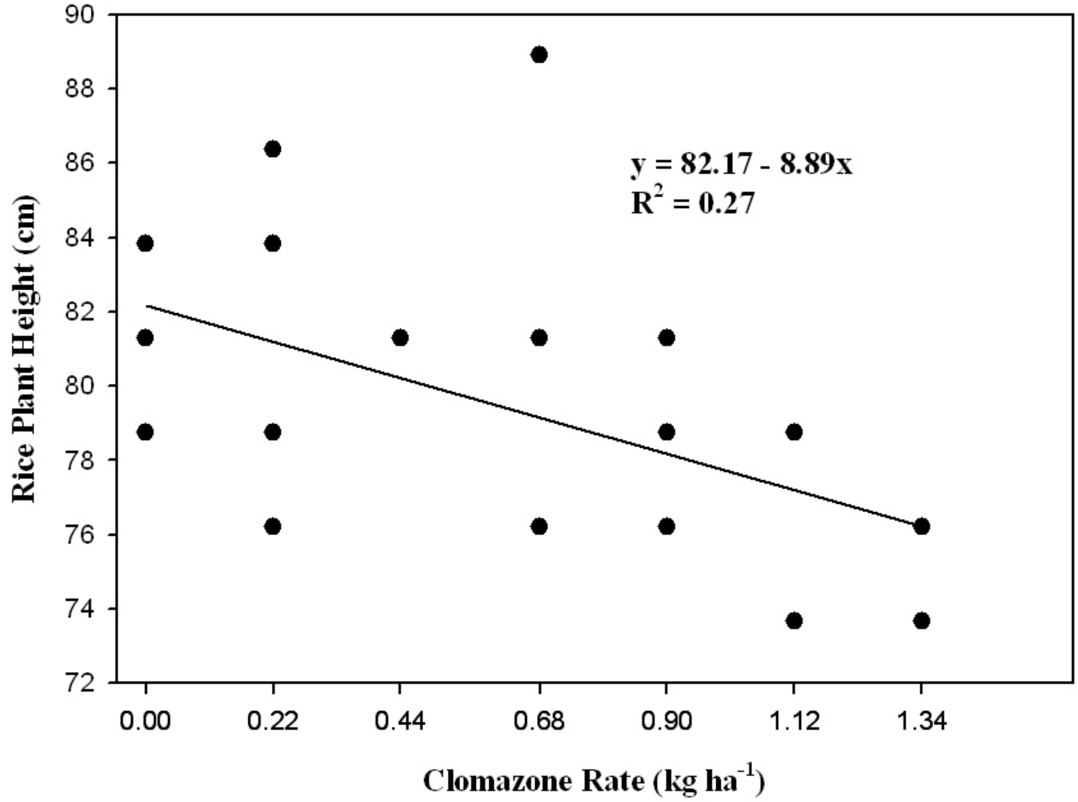

Figure 5. Standard curve experiment regression analysis of plant height 62 DAP at Ganado, TX.

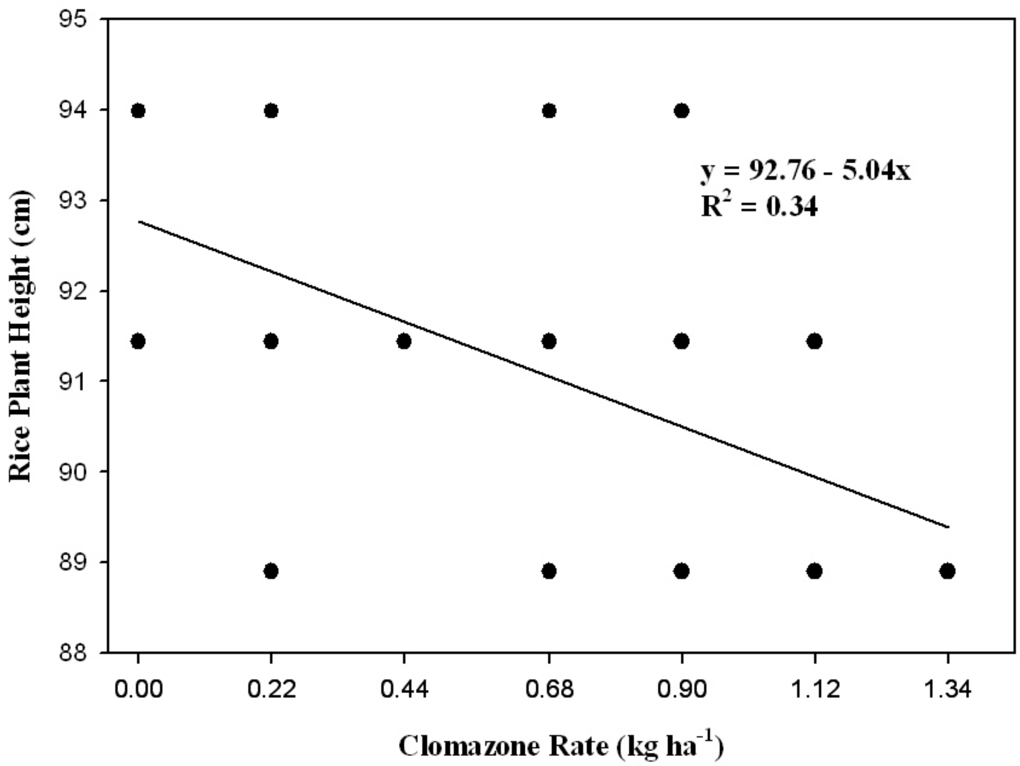

Figure 6. Standard curve experiment regression analysis of plant height 71 DAP at Ganado, TX.

Visual injury ratings were recorded three times during the study and were statistically analyzed. Following an initial ANOVA, no statistical differences were observed in any visual rating event. Plant height was also measured at three times during the field study. Plant height was statistically different among the fertility treatments in each plant measurement event.

During the first plant height rating, the fertility treatment showing the highest numerical mean was observed in the treatment receiving 292 kg ha^{-1} urea and 1% w/w iron sulfate foliar fertilizer at the LPOST application timing (Table 14). The treatment with the lowest numerical mean was observed in the treatment receiving 1% w/w iron sulfate and 0.5% w/w of magnesium sulfate foliar fertilizers, which was similar to the control. All treatments receiving the highest initial rate of N at 134 kg ha^{-1} were not different from all other treatments except for the treatment receiving 134 kg ha^{-1} in the form of ammonium sulfate. All treatments receiving only foliar micronutrient fertilizers and the untreated check were not different from each other and produced the shortest plants.

At the second plant height measurement made 76 DAP, most treatments receiving N fertility amendments had taller plants and were not different from other N treated plots (Table 15). The treatments receiving the lowest rate of ammonium sulfate and the treatment receiving lower rates of urea in a split application had mean plant heights of 83 and 84 cm, respectively, and were different from other N treatments. The numerically greatest plant height mean was observed in the treatment receiving 134 kg ha^{-1} N from urea and 1% w/w foliar-applied iron sulfate. This treatment also contained

Table 14. Plant height 67 DAP at Eagle Lake, TX.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
AS	320	67	LPOST	76 bcd
AS	640	134	LPOST	74 d
Urea	146	67	LPOST	75 cd
Urea	292	134	LPOST	81 ab
Urea	110	50	LPOST	74 d
Urea	146	67	PREFLOOD	
Urea	219	101	LPOST	76 bcd
Urea	146	67	PREFLOOD	
IS[b]	1% w/w	0	LPOST	59 e
AS	320	67	LPOST	78 abcd
IS	1% w/w	0	LPOST	
AS	640	134	LPOST	80 abc
IS	1% w/w	0	LPOST	
Urea	292	134	LPOST	84 a
IS	1% w/w	0	LPOST	
Urea	219	101	LPOST	79 abcd
IS	1% w/w	0	LPOST	
Urea	146	67	PREFLOOD	
MS[c]	0.5% w/w	0	LPOST	59 e
IS	1 % w/w	0	LPOST	57 e
MS	0.5 % w/w	0	LPOST	

Table 14. Continued.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
Non-amended Control	0	0	-----	58 e

[a]Abbreviations: LPOST, late postemergence applied 4- to 6-leaf rice; PREFLOOD, preflood application timing; AS, ammonium sulfate; IS, iron sulfate; MS, magnesium sulfate; DAP, days after planting.
[b]Mixed and applied as a foliar spray in a 1% solution.
[c]Mixed and applied as a foliar spray in a 1% solution.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Table 15. Plant height 76 DAP at Eagle Lake, TX.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
AS	320	67	LPOST	83 c
AS	640	134	LPOST	89 abc
Urea	146	67	LPOST	87 abc
Urea	292	134	LPOST	92 a
Urea	110	50	LPOST	84 bc
Urea	146	67	PREFLOOD	
Urea	219	101	LPOST	90 ab
Urea	146	67	PREFLOOD	
IS[b]	1% w/w	0	LPOST	71 d
AS	320	67	LPOST	87 abc
IS	1% w/w	0	LPOST	
AS	640	134	LPOST	90 ab
IS	1% w/w	0	LPOST	
Urea	292	134	LPOST	93 a
IS	1% w/w	0	LPOST	
Urea	219	101	LPOST	91 a
IS	1% w/w	0	LPOST	
Urea	146	67	PREFLOOD	
MS[c]	0.5% w/w	0	LPOST	72 d
IS	1 % w/w	0	LPOST	72 d
MS	0.5 % w/w	0	LPOST	

Table 15. Continued.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
Non-amended Control	0	0	-----	72 d

[a]Abbreviations: LPOST, late postemergence applied 4- to 6-leaf rice; PREFLOOD, preflood application timing; AS, ammonium sulfate; IS, iron sulfate; MS, magnesium sulfate; DAP, days after planting.
[b]Mixed and applied as a foliar spray in a 1% solution.
[c]Mixed and applied as a foliar spray in a 1% solution.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

the tallest rice plants in the previous plant height assessment. All treatments receiving only foliar-applied micronutrient fertilizers and the non-amended control had the shortest rice plants and were not different from other plots receiving only micronutrients. The treatment with the numerically lowest plant height mean was the treatment receiving only 1% w/w iron sulfate.

At the third plant height measurement made 95 DAP, all treatments receiving N were similar, producing the tallest plants (Table 16). Plants as tall as 122 cm were observed in three different treatments receiving N. All treatments receiving only foliar-applied micronutrient fertilizers and the non-amended control had the shortest plants. The treatment with the lowest numerical plant height mean of 91 cm was observed in the treatment receiving 1% w/w iron sulfate and 0.5% magnesium sulfate.

At the conclusion of the laboratory procedure for determining chlorophyll content, data were analyzed by ANOVA. Chlorophyll concentrations from the first and second tissue sampling events were not statistically different. Chlorophyll content was statistically different between fertility treatments in the third and final tissue sample event, however (Table 17.) One treatment receiving only 1% w/w foliar applied iron sulfate was statistically different from chlorophyll concentration in all other treatments. This treatment produced the lowest numerical mean for chlorophyll concentration of 0.86 mg g^{-1} on a fresh weight basis, but was statistically similar to the control and several treatments receiving nitrogen. The treatment with the highest numerical mean for chlorophyll concentration was the treatment receiving a split application of urea. This

Table 16. Plant height 95 DAP at Eagle Lake, TX.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
AS	320	67	LPOST	114 a
AS	640	134	LPOST	120 a
Urea	146	67	LPOST	113 a
Urea	292	134	LPOST	120 a
Urea	110	50	LPOST	116 a
Urea	146	67	PREFLOOD	
Urea	219	101	LPOST	122 a
Urea	146	67	PREFLOOD	
IS[b]	1% w/w	0	LPOST	95 b
AS	320	67	LPOST	122 a
IS	1% w/w	0	LPOST	
AS	640	134	LPOST	121 a
IS	1% w/w	0	LPOST	
Urea	292	134	LPOST	121 a
IS	1% w/w	0	LPOST	
Urea	219	101	LPOST	122 a
IS	1% w/w	0	LPOST	
Urea	146	67	PREFLOOD	
MS[c]	0.5% w/w	0	LPOST	93 b
IS	1 % w/w	0	LPOST	91 b
MS	0.5 % w/w	0	LPOST	

Table 16. Continued.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
Non-amended Control	0	0	-----	93 b

[a]Abbreviations: LPOST, late postemergence applied 4- to 6-leaf rice; PREFLOOD, preflood application timing; AS, ammonium sulfate; IS, iron sulfate; MS, magnesium sulfate;DAP, days after planting.
[b]Mixed and applied as a foliar spray in a 1% solution.
[c]Mixed and applied as a foliar spray in a 1% solution.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

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Table 17. Chlorophyll concentration of rice tissue 76 DAP at Eagle Lake, TX.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Chlorophyll Content (mg g^{-1} fresh w/w)[d]
AS	320	67	LPOST	1.74 ab
AS	640	134	LPOST	1.82 ab
Urea	146	67	LPOST	2.10 ab
Urea	292	134	LPOST	1.74 ab
Urea	110	50	LPOST	2.33 a
Urea	146	67	PREFLOOD	
Urea	219	101	LPOST	1.81 ab
Urea	146	67	PREFLOOD	
IS	1% w/w	0	LPOST	0.86 b
AS	320	67	LPOST	1.53 ab
IS	1% w/w	0	LPOST	
AS	640	134	LPOST	1.85 ab
IS	1% w/w	0	LPOST	
Urea	292	134	LPOST	1.44 ab
IS	1% w/w	0	LPOST	
Urea	219	101	LPOST	1.32 ab
IS	1% w/w	0	LPOST	
Urea	146	67	PREFLOOD	
MS	0.5% w/w	0	LPOST	1.18 ab

Table 17. Continued.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Chlorophyll Content (mg g^{-1} fresh w/w)[d]
IS	1 % w/w	0	LPOST	1.08 ab
MS	0.5 % w/w	0	LPOST	
Non-amended Control	0	0	-----	1.26 ab

[a]Abbreviations: LPOST, late postemergence applied 4- to 6-leaf rice; PREFLOOD, preflood application timing; AS, ammonium sulfate; IS, iron sulfate; MS, magnesium sulfate; DAP, days after planting.
[b]Mixed and applied as a foliar spray in a 1% solution.
[c]Mixed and applied as a foliar spray in a 1% solution.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

treatment received 50 kg ha^{-1} at the LPOST timing and 67 kg ha^{-1} at the PREFLOOD timing. Mean chlorophyll concentration of this fertility treatment was 2.33 mg g^{-1}.

Yield data recorded at the conclusion of the study was not statistically different in any treatment and is not shown. Panicle blight was observed at the Eagle Lake research location during the growing season this study was conducted. This was most likely the cause of a very uniform yield as control plots receiving no fertility yielded the same as plots receiving high rates of nitrogen fertilizers.

Ganado. *Clomazone injury recovery.* Test parameters were the same parameters evaluated at Eagle Lake. Visual injury ratings, plant height, chlorophyll content, and yield were assessed at this research location. Visual injury was assessed at three different timings during the study and subjected to statistical analysis. After an ANOVA was performed, no statistical difference was observed in any of the visual rating events. Plant height was statistically different among fertility treatments at all plant measurement dates.

At the first plant height measurement at 62 DAP, all treatments receiving N fertilizers regardless of form or rate produced rice plants with no statistical difference in height (Table 18). The numerically greatest height of 76 cm was observed in treatments with ammonium sulfate applied at the highest rate. The control receiving no additional fertility amendments along with treatments consisting of only foliar-applied micronutrient fertilizers produced the shortest rice plants, and were different from all other treatments containing N. The numerically lowest treatment means for plant height

Table 18. Plant height 62 DAP at Ganado, TX.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
AS	320	67	LPOST	68 ab
AS	640	134	LPOST	76 a
Urea	146	67	LPOST	68 ab
Urea	292	134	LPOST	74 a
Urea	110	50	LPOST	68 ab
Urea	146	67	PREFLOOD	
Urea	219	101	LPOST	71 a
Urea	146	67	PREFLOOD	
IS[b]	1% w/w	0	LPOST	62 b
AS	320	67	LPOST	69 ab
IS	1% w/w	0	LPOST	
AS	640	134	LPOST	76 a
IS	1% w/w	0	LPOST	
Urea	292	134	LPOST	75 a
IS	1% w/w	0	LPOST	
Urea	219	101	LPOST	71 a
IS	1% w/w	0	LPOST	
Urea	146	67	PREFLOOD	
MS[c]	0.5% w/w	0	LPOST	61 b

Table 18. Continued.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
IS	1 % w/w	0	LPOST	61 b
MS	0.5 % w/w	0	LPOST	
Non-amended Control	0	0	-----	62 b

[a]Abbreviations: LPOST, late postemergence applied 4- to 6-leaf rice; PREFLOOD, preflood application timing; AS, ammonium sulfate; IS, iron sulfate; MS, magnesium sulfate; DAP, days after planting.
[b]Mixed and applied as a foliar spray in a 1% solution.
[c]Mixed and applied as a foliar spray in a 1% solution.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

were 61 cm in the treatments receiving 1% w/w iron sulfate, and 1% w/w iron sulfate and 0.5% w/w magnesium sulfate tank-mixed.

At the second plant height measurement made 71 DAP, treatments receiving the higher rates of N at the LPOST timing produced numerically higher plant heights than other treatments (Table 19). The highest plant height mean in any one treatment was 93 cm and was observed in the treatment with 134 kg ha^{-1} N from urea and 1% w/w iron sulfate. The lowest plant height means were in all treatments receiving only foliar-applied iron sulfate and magnesium sulfate along with the non-amended control.

Plant height measurement means at the third measurement collected 90 DAP were statistically similar in all treatments except the treatment receiving only 0.5% w/w magnesium sulfate (Table 20). This treatment produced the smallest plant height mean of 105 cm. The numerically highest plant height mean of 124 cm was observed in the treatment receiving a split application of urea at rates of 101 kg ha^{-1} and 67 kg ha^{-1} N at LPOST and PREFLOOD, respectively. All other treatments were not statistically different.

Following laboratory analysis for chlorophyll content in tissue samples, data were subjected to ANOVA. No statistical differences were noted among fertility treatments at any of the three tissue sampling dates. Yield data were collected at the conclusion of the study and also subjected to statistical analysis. The highest mean yield of 10,208 kg ha^{-1} was observed in the treatment receiving a split application of urea at rates of 101 kg ha^{-1} and 67 kg ha^{-1} N at LPOST and PREFLOOD, respectively (Table 21). This treatment also had the highest numerical mean for plant height at the final plant

Table 19. Plant height 71 DAP at Ganado, TX.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
AS	320	67	LPOST	85 abc
AS	640	134	LPOST	92 a
Urea	146	67	LPOST	82 bcd
Urea	292	134	LPOST	93 a
Urea Urea	110 146	50 67	LPOST PREFLOOD	88 ab
Urea Urea	219 146	101 67	LPOST PREFLOOD	89 ab
IS[b]	1% w/w	0	LPOST	76 cd
AS IS	320 1% w/w	67 0	LPOST LPOST	83 abcd
AS IS	640 1% w/w	134 0	LPOST LPOST	92 a
Urea IS	292 1% w/w	134 0	LPOST LPOST	93 a
Urea IS Urea	219 1% w/w 146	101 0 67	LPOST LPOST PREFLOOD	90 ab
MS[c]	0.5% w/w	0	LPOST	74 d

Table 19. Continued.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
IS	1 % w/w	0	LPOST	75 d
MS	0.5 % w/w	0	LPOST	
Non-amended Control	0	0	-----	77 cd

[a]Abbreviations: LPOST, late postemergence applied 4- to 6-leaf rice; PREFLOOD, preflood application timing; AS, ammonium sulfate; IS, iron sulfate; MS, magnesium sulfate; DAP, days after planting.
[b]Mixed and applied as a foliar spray in a 1% solution.
[c]Mixed and applied as a foliar spray in a 1% solution.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Table 20. Plant height 90 DAP at Ganado, TX.

Fertility Amendments[a]	Formulated Fertilizer Applied (ka ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
AS	320	67	LPOST	117 a
AS	640	134	LPOST	120 a
Urea	146	67	LPOST	118 a
Urea	292	134	LPOST	120 a
Urea Urea	110 146	50 67	LPOST PREFLOOD	123 a
Urea Urea	219 146	101 67	LPOST PREFLOOD	124 a
IS[b]	1% w/w	0	LPOST	114 ab
AS IS	320 1% w/w	67 0	LPOST LPOST	121 a
AS IS	640 1% w/w	134 0	LPOST LPOST	120 a
Urea IS	292 1% w/w	134 0	LPOST LPOST	119 a
Urea IS Urea	219 1% w/w 146	101 0 67	LPOST LPOST PREFLOOD	122 a
MS[c]	0.5% w/w	0	LPOST	105 b

Table 20. Continued.

Fertility Amendments[a]	Formulated Fertilizer Applied (ka ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Plant Height (cm)[d]
IS	1 % w/w	0	LPOST	115 ab
MS	0.5 % w/w	0	LPOST	
Non-amended Control	0	0	-----	114 ab

[a]Abbreviations: LPOST, late postemergence applied 4- to 6-leaf rice; PREFLOOD, preflood application timing; AS, ammonium sulfate; IS, iron sulfate; MS, magnesium sulfate; DAP, days after planting.
[b]Mixed and applied as a foliar spray in a 1% solution.
[c]Mixed and applied as a foliar spray in a 1% solution.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

Table 21. Rice grain yield in the injury remediation experiment near Ganado, TX.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Rice Grain Yield (kg ha^{-1})[d]
AS	320	67	LPOST	9112 ab
AS	640	134	LPOST	10087 a
Urea	146	67	LPOST	9528 a
Urea	292	134	LPOST	10404 a
Urea Urea	110 146	50 67	LPOST PREFLOOD	9174 ab
Urea Urea	219 146	101 67	LPOST PREFLOOD	10208 a
IS[b]	1% w/w	0	LPOST	7754 c
AS IS	320 1% w/w	67 0	LPOST LPOST	9672 a
AS IS	640 1% w/w	134 0	LPOST LPOST	9999 a
Urea IS	292 1% w/w	134 0	LPOST LPOST	10078 a
Urea IS Urea	219 1% w/w 146	101 0 67	LPOST LPOST PREFLOOD	9912 a
MS[c]	0.5% w/w	0	LPOST	7843 bc

Table 21. Continued.

Fertility Amendments[a]	Formulated Fertilizer Applied (kg ha^{-1})	Nitrogen Applied (kg ha^{-1})	Application Timing	Rice Grain Yield (kg ha^{-1})[d]
IS	1 % w/w	0	LPOST	7713 c
MS	0.5 % w/w	0	LPOST	
Non-amended Control	0	0	-----	7443 c

[a]Abbreviations: LPOST, late postemergence applied 4- to 6-leaf rice; PREFLOOD, preflood application timing; AS, ammonium sulfate; IS, iron sulfate; MS, magnesium sulfate; DAP, days after planting.
[b]Mixed and applied as a foliar spray in a 1% solution.
[c]Mixed and applied as a foliar spray in a 1% solution.
[d] Means followed the same letter are not different according to Tukey's test ($P \leq 0.05$).

height measurement date. All treatments receiving fertility amendments containing N were not statistically different in rice grain yield. The lowest numerical mean yield value of 7443 kg ha^{-1} was observed in the non-amended control, however this treatment was not different in yield from the three treatments receiving only foliar-applied micronutrient fertilizers.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Clomazone is an effective herbicide for the control of grassy weeds in rice production systems. Early season rice injury that can potentially occur from clomazone use has been studied in the past. Herbicide injury from clomazone might overshadow the effectiveness of the compound, thus decreasing its use. The focus of this research was to evaluate agronomic practices and their influence, if any, on clomazone behavior within a rice production system. Proper seeding density and fertility programs are two practices necessary to maximizing productivity of rice cropping systems.

Work was done to evaluate the role that seeding density, planting date and soil characteristics had on clomazone uptake in rice plants based on visual injury assessments and rice grain yield. Because hybrid rice varieties have lower recommended planting densities compared to conventional varieties, the potential increase in clomazone uptake from fewer seedlings in the field was initially regarded as a potential problem leading to an increase in clomazone injury severity. Based on field studies with three planting rates and two planting dates, the data suggested that seeding rate did not play a significant role in clomazone injury. Planting date and soil texture, however, did have significant effects on clomazone injury. Coarse-textured soils common to some areas in the western rice-growing region will produce more severe clomazone injury symptoms on rice, most likely related to a decrease in clay content which has been shown to affect clomazone behavior in the soil environment. Planting date also had a significant effect on the severity of clomazone injury symptoms. Rice planted at an early planting date within the planting window recommended by production guidelines showed increased clomazone injury. Cooler temperatures at a March planting date might reduce the overall metabolic activity of the rice plant, in turn reducing the plant's ability to effectively metabolize the herbicide.

At the conclusion of this study and as suggested in past research, rice injury did not translate into yield loss. Based on the findings of this research effort, following recommendations published in Texas Rice Production Guidelines including seeding rate and time of planting are the best management practices for Texas rice production systems utilizing clomazone herbicide in hybrid rice varieties.

The purpose of the second portion of this study was to evaluate the effects that soil fertility might have on rice injured with clomazone. Because fertility amendments are applied at multiple times throughout the growing season, it would be easy to manipulate timing and rates of application if a certain treatment decreased the time that clomazone injury was visible. Clomazone injury remediation would also come at little or no additional cost to the producer with the amendments that were assessed in this study since nitrogen fertilizers would be applied to enhance productivity of the system. Foliar-applied micronutrients were also included within the test since these fertilizers are usually inexpensive when compared to other compounds.

Based on the findings of this research effort, visual injury symptoms from clomazone were not reduced in severity by fertilizers applied in the study. Plant height was affected by fertility treatments at both study locations. Yield was affected by fertility treatments at the Ganado location but the occurrence of panicle blight at the

Eagle Lake location negatively affected yield potential of plants receiving high rates of fertility. Increasing the amount of N produced taller rice plants and increased yield at the Ganado location. In the standard curve experiment, increased clomazone injury was observed as the rate applied increased. Yield results from this experiment suggested that clomazone use can increase yield by reducing weed competition with rice plants. These observations further support the conclusions reached in past research efforts. Based on the conclusion of this study, standard fertility programs recommended in production guidelines, along with recommended management and cultural practices should be followed when using clomazone herbicide in rice production systems to best maximize rice grain yield potential.

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